A Policy Recommendation for the Reduction of Tree Crashes

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ABSTRACT

Trees contribute to the aesthetics of roadways but they are also the objects struck in approximately 3,000 fatal crashes annually in the United States. While the removal of roadside trees would undoubtedly reduce the number of fatal crashes with trees, it would not provide for an acceptable aesthetic environment. Balancing the positive aesthetic contribution of trees with the negative highway safety aspects of trees should be addressed in order to maximize both safety and aesthetics where possible.

Creating roadway environments that are both safe and aesthetically pleasing requires an understanding of the correlations between various highway design factors and the possibility of a tree crash. Understanding these correlations will allow public policy making agencies to develop tree placement and maintenance procedures which maximize roadside tree preservation and minimize the likelihood of tree crashes.

This study determined that rural collectors are the functional classification of road most prone to tree crashes; reviewed several roadway characteristics (i.e., horizontal curve, vertical curve, speed limit, clear zone, tree density, etc.); and determined speed limit, tree density and clear zone contribute most to predicting the locations of tree crashes in Massachusetts. Using this information, a regression equation to predict tree crashes based on highway characteristics was developed and a proposed tree policy for new highway construction and reconstruction, which maximizes the preservation of existing trees and predicts safe locations for proposed tree plantings is presented. Furthermore, a procedure for implementation by maintenance personal, for assessing locations which pose potential risk was developed and is presented.

INTRODUCTION

Crashes with trees kill approximately 3,000 people each year in the United States and account for 28% of the crashes with fixed objects (Ivey & Zeger 2004). While trees are a significant roadside hazard, they also contribute considerably to the roadside environment and aesthetics. "There is a strong movement nationally to maintain and preserve historic and scenic resources during construction and reconstruction of highways." The American Association of State Highway and Transportation Officials (AASHTO) "…encourages a comprehensive view of the design situation…." (AASHTO 2008) The Roadside Design Guide suggests that "to promote consistency within a State, each highway agency should develop a formal policy to provide guidance to design, landscape, construction, and maintenance personnel for this situation," (AASHTO 2006) yet little guidance exists in literature.

This study reviewed the 2005 tree crash records within the Massachusetts Highway Department (MassHighway) District Three boundaries, the characteristics of a route within those boundaries, and developed strategies to minimize roadside tree crashes throughout the highway network while maintaining the roadside environment. This paper presents a methodology for developing a tree crash prediction model and the model developed for Massachusetts; a proposed policy for the placement and maintenance of roadside trees during a new highway construction or reconstruction project, which reduces tree crash risk; and a proposed maintenance procedure for the identification and ranking of roadway segments for tree crash risk abatement.

OBJECTIVE

Roadside trees are located adjacent to the roadway within the public right-of-way. Roadside trees often provide beauty and act as buffers between roadways and adjacent land users. Roadside trees, however, can significantly reduce visibility on curves and at intersections and they can be a hazard when hit by wayward vehicles.

An easy solution to improve roadside safety would be to remove trees from the roadside. This would certainly decrease the number of roadside hazards but result in an unacceptable aesthetic environment to road users, property owners and other stake holders. Removing trees entirely from the public right-of-way, therefore, is not a viable option. A better approach is to understand the highway design factors that make some trees more potentially harmful than other trees and to develop strategies for identifying these most hazardous trees. The objectives of this study were to review 2005 MassHighway District Three tree crashes to understand the relationship between highway characteristics and tree crash risk and present a proposed policy for possible implementation in design, construction and maintenance of the roadside environment. The objectives of this policy are to balance the aesthetics roadside trees provide with the risk for tree crashes by identifying and removing or shielding high-risk trees while maintaining low-risk trees.

BACKGROUND

The U.S. Department of Transportation published *Guide to Management of Roadside Trees* in December, 1986. At that time, an average of 3,000 crashes with trees occurred each year in the US. (USDOT 1986) AASHTO developed the *Strategic Highway Safety Plan* (2008) in an attempt to reduce the frequency and severity of crashes on highways in the United States. Trees are addressed in section "17-18(3), Trees in Hazardous Locations." The *Strategic Highway Safety Plan* (2008) found that the 1999 Fatal Accident Reporting System data indicates 10,967 fatal crashes involved a fixed object. Trees were struck more often than any other fixed object accounting for 3,010 fatal crashes. This finding is consistent with the *Guide to Management of Roadside Trees* study 10 years earlier. (USDOT 1986)

The Strategic Highway Safety Plan (2008) provides a distribution of fatal crashes by roadway functional classification as shown in Figure 1. This study found that "fatal tree crashes were most prevalent on local rural roads, followed by major rural collectors." This study also found that 90 percent of the fatal tree crashes occurred on two-lane roads while only five percent occurred on four-lane roads. (AASHTO 2008)

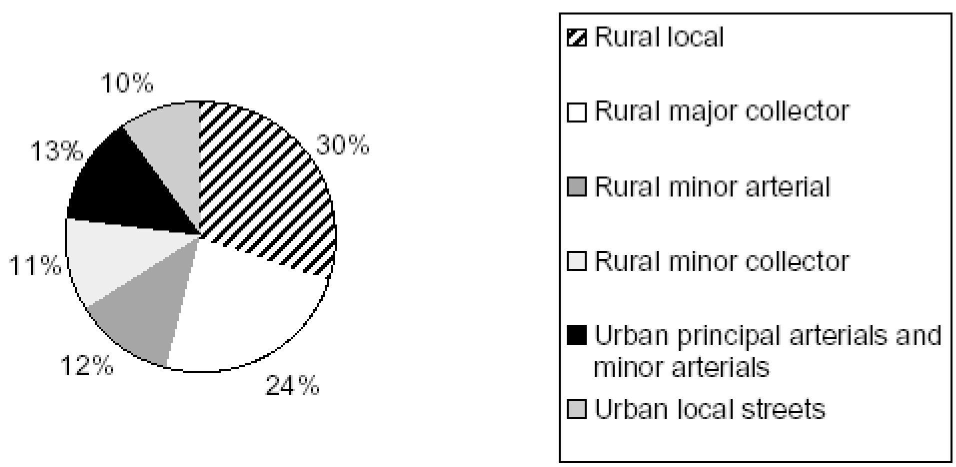

Figure 1. Distribution of fatal tree collisions by functional classification.

DETERMINATION OF MASSACHUSETTS TREE CRASH RISK

The objective of this phase of the research was to determine whether Massachusetts data corresponds with national finding and what is the distribution of risk, by functional classification, of being involved in a tree crash. Tree crash rates were chosen rather than crash frequency as a means of comparison. Crash rates are a common way of comparing different locations with different traffic volume. The crash rate represents the risk of becoming involved in a particular kind of crash each time a vehicle traverses the highway segment. A crash rate is calculated by determining the number of crashes in a particular category (e.g. tree crashes) occurring during a study period, multiplying by 100 million and dividing by the average traffic volume for that study period and the length of the segment, as shown here:

$$\frac{\text{(2005 Tree Crashes) * 100,000,000}}{\text{(Length in KM)* ADT * 365 days/year}} = \text{Crashes/100 MVKMT}$$

This crash rate is reported in crashes per 100,000,000 vehicle kilometers traveled (100 MVKMT). If, for example, the crash rate on a particular one-kilometer long road segment is 1.00 crashes per 100 MVKMT, it means that on average one crash occurs for every 100 million vehicles that pass through a 1 km long segment.

When crash statistics are compared for large geographical regions, it can be cumbersome to use crash rates, therefore, crash frequency expressed as a percentage is sometimes used as AASHTO did in the *Strategic Highway Safety Plan.* (2008)

Study Area Tree Crashes

Tree crashes occurring within District Three were tabulated using the 2005 crash records database obtained from MassHighway, which obtains crash data from the Massachusetts Registry of Motor Vehicles (RMV) for use in engineering studies. This data is provided to the user in the form of an individual Excel file for an entire city or town for an entire year. Data for a single roadway is not available but can be summarized from the Excel file for an individual town. Crashes are listed individually in the city/town data files. Each crash includes information obtained from the RMV crash data including the date, time, number of vehicles involve, crash severity, weather and lighting conditions, and crash location information and the manner of the collision. Crash records are displayed in a tabular format. The 2005 data set included Massachusetts Mainland State Plane NAD 83 meters coordinates for crashes that have been geo-coded to an approximate location based on available crash location data. (Massachusetts Highway Department, 2007) This geo-referencing could be useful for future safety tracking.

Review of Available Traffic Data

Average Daily Traffic (ADT) volumes are collected using automatic traffic recorders or weigh-in-motion (WIM) sensors at permanent and temporary traffic counting locations. These traffic counts are gathered for a number of reasons varying from local development to traffic growth charting. This data is maintained by area planning agencies and MassHighway. Available traffic information was gathered from MassHighway and the regional planning agencies whose boundaries overlap District Three, including the Montachusett Regional Planning Commission, Metropolitan Area Planning Council, Central Massachusetts Regional Planning Commission, and the Northern Middlesex Council of Governments. This data was used to calculate the crash rates.

Functional Classification of the Roadway

MassHighway maintains a Geographic Information System (GIS) of the functional classification of roads in the Commonwealth. This GIS database was queried to produce a list of roads by functional classification. This list was cross-referenced with the list of tree crash locations to categorize the tree crashes by functional classification.

Determination of Average Tree Crash Risk by Functional Classification

Crash rates, injury crash rates and fatal crash rates for tree crashes occurring in 2005 within District Three were calculated, as outlined above, for each functional classification of roadway and the results are shown in Table 1.

Rural minor collectors experienced a crash rate of 24.0 tree crashes per 100 MVKMT and 7.6 injury tree crashes per 100 MVKMT, the functional classification with the highest crash rate in the District Three study area. This functional classification, however, did not experience any fatal tree crashes during the study period. Rural major collectors experienced a slightly lower crash rate of 13.4 tree crashes per 100 MVKMT, 6.8 injury tree crashes per 100 MVKMT and 0.4 fatal tree crashes per 100 MVKMT. Conversely, it was found that interstates and arterials experienced the lowest crash rates in 2005 as shown in Table 1. In fact, the tree crash rate on minor rural collectors was about 20 times higher than the tree crash rate on interstate highways.

Table 1: Summary of 2005 Massachusetts District Three Tree Crash Rates by Functional Classification.

Functional Classification	Crash Rate per 100 MVKMT	Injury Rate per 100 MVKMT	Fatal Rate per 100 MVKMT
Rural Minor Collector	24.0	7.6	0.0
Rural Major Collector	13.4	6.8	0.4
Urban Collector	7.3	3.1	0.0
Rural Local	5.6	3.6	0.0
Rural Minor Arterial	4.3	2.3	0.0
Urban Minor Arterial	3.4	1.5	0.1
Urban Local	1.7	0.7	0.0
Urban Principal Arterial	1.3	0.7	0.0
Interstates	1.2	0.7	0.1
Urban Other Principal Arterial	1.1	0.4	0.1
Rural Principal Arterial	0.8	0.8	0.0

Every region has unique highway geometric and tree placement characteristics, therefore, this step should be taken for any region to establish average tree crash rates for that region. The average tree crash rate can be used as a baseline for which to establish the need for further study of existing roadways (e.g., roads with rates above the average warrant study) or as a guideline when designing new landscaping.

Highway Characteristics Contributing to Tree Crash Risk
Upon determining that rural major and minor collectors experience the highest tree crash risk in District Three, Route 31 in Spencer, Massachusetts was identified as a route for detailed data collection to develop a predictor model for determining which characteristics of the highways are contributing to the tree crashes and to which magnitude each characteristic contributes. Route 31, within the boundaries of Spencer, Massachusetts, experiences a tree crash rate of 26.15 per 100MVKMT, an Injury Tree Crash Rate of 14.94 per 100 MVKMT, clearly above the average of other Rural Minor and Rural Major Collectors in District Three, which this ten-mile section of road is classified as.

To conduct data collection, Route 31 was divided into segments of 161 meters (0.1 miles) in length. Crash rates for each segment were then calculated, as shown in Figure 2. Some segments of the Route show a higher crash rate than others. The maximum crash rate was 370 per 100 MVKMT. The minimum was zero. This illustrates that tree crashes appear to cluster at particular locations presumably with particular characteristics.

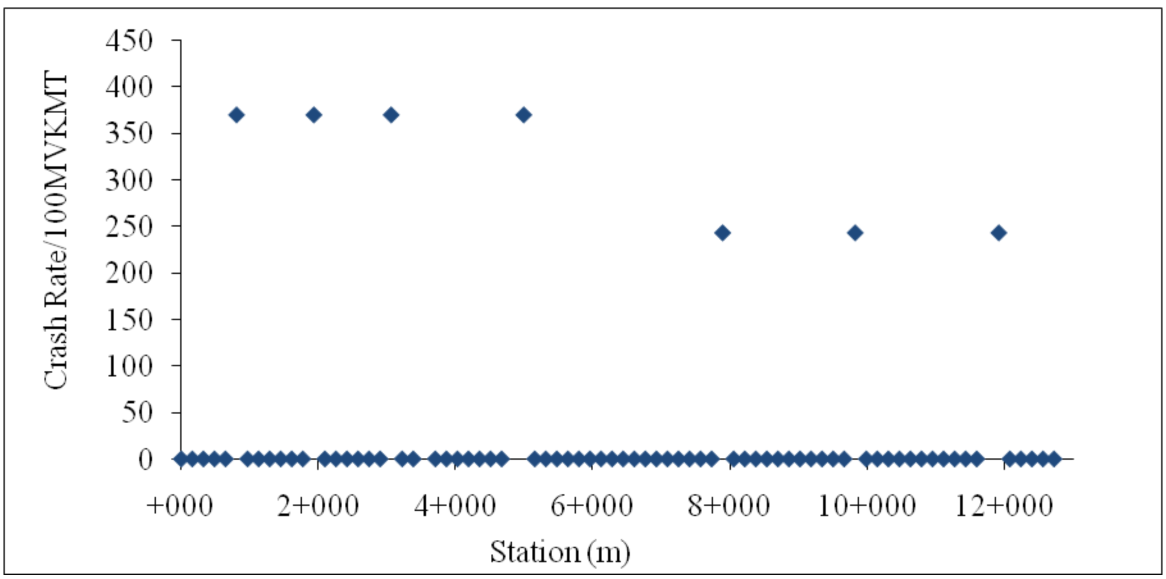

Figure 2. Actual 2005 Crash Rates along Route 31 in Spencer, MA by 161 meter segment.

The first objective of this phase was to understand if there was any relation between the crash rates and the characteristics of the segments. Segments with high risk and with low risk were both considered so as to avoid possibly identifying tree crash risk indicators which are also prevalent in the low risk segments.

Individual segment data collected included: the posted speed limit (km/h); tree density, collected as the number of trees along a seven meter representative section of frontage; the radius of horizontal curvature of the segment (zero if tangent); the absolute value of the grade of the vertical alignment (expressed in percent); and clear zone to trees (meters). Conron *et al* discuss the details of the data collection procedures employed in “*Using Public Information and Graphics Software in Graduate Highway Safety Research at Worcester Polytechnic Institute*.” (Conron et al. 2009)

Collected data was superimposed individually on the crash rate graph, as shown in Figure 3 to determine if there is any obvious link between each individual characteristic and the risk of tree crashes.

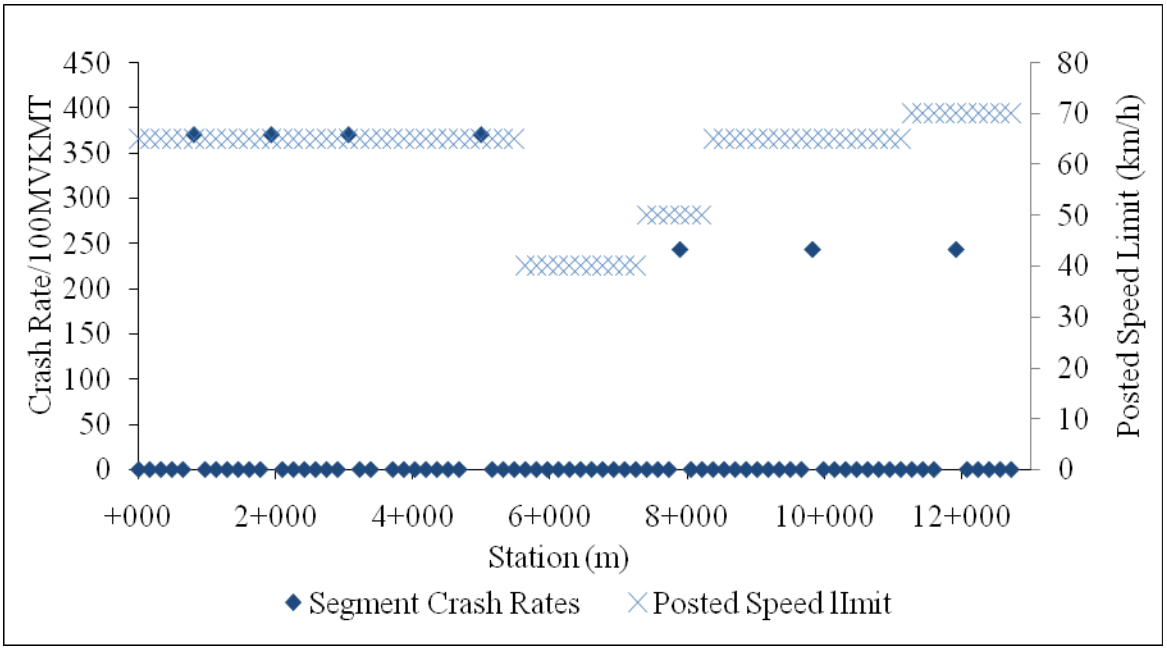

Figure 3. Actual 2005 Crash Rates Compared to Posted Speed Limit.

This type of analysis was conducted for all of the collected highway characteristics. The ADT did not seem to be correlated with higher or lower crash rates since tree crashes occurred throughout this route, which experiences variations in traffic volumes, north and south of the Town center. On the contrary, it is evident that speed limit would be an important parameter to consider further when predicting which road locations have a potentially higher risk than others. From the graph, it is clear that no crashes with trees happened in the segments with the lowest speed limit. Tree crash risk increases where the speed limit increases; in those segments, a consistently higher tree crash rate is recorded in 2005. Additional analysis identified tree density to be an important parameter; however, no obvious dependency is apparent between the recorded number of tree crashes and any individual highway characteristic of Route 31. Despite expectations, the relationship between the crash rates with the segment clear zone values is not evident from this type of analysis.

This simple approach for examining the influence of road characteristics on recorded tree crashes was helpful to identify which factors are influencing tree crashes, but did not indicate what level of influence each parameter has on the tree crash rate.

Zone Analysis: It was clear, from Figure 2, that there were some segments in Route 31 with a higher tree crash rate than other segments. Route 31 travels through five distinct land use zones. The impact of the land use on tree crash risk was evaluated through dividing the Route 31 and the collected data into five zones by their land use. An average value of the collected data was considered and evaluated (Table 2):

1. "Forest" (wood region),
2. "Downtown" (downtown area of Spencer town),
3. "Residential1" (immediately outside downtown Spencer, residential area),
4. "Residential2" (residential area less populated than residential area 1 approaching the field region), and
5. "Field" (field-country zone).

Table 2: Summary of characteristics of each zone of Route 31 in Spencer.

	Forest	Downtown	Residential1	Residential2	Field
Location (m)	2737	6440	7889	9821	12075
Average ADT	4600	5255	7000	7000	7000
Average Speed limit	65	40	50	65	70
Average tree density	51	28	26	39	73
Average Curvature	6727	6448	5100	6813	6155
Average Grade	2.8	3.8	4.8	2.4	1.9
Average Clear Zone	4.0	6.6	8.7	4.2	4.9
Crash Rate	174.086259	0	4.96120462	3.985229941	16.2066

Once again, the crash risk was superimposed along a graph of the highway characteristics, this time by land use zone. This analysis confirmed the results of the first approach used above, and from what it are reported on the "*Roadside Design Guide*": "There are many reasons why a vehicle will leave the pavement and encroach on the roadside, including … excessive speed …." (AASHTO 2006) From the graph, it appeared that the tree crash risk is greater in zones where the average speed limit was higher. More interestingly, from Figures 4 and 5, it appears that there is a connection between the tree crash risk and both tree density and clear zone values. This time, using larger data samples (e.g., the land use zones), it is possible to identify the increase of tree crash risk with respect to the tree density of the segment and the clear zone. When the density of trees is higher, there is more chance for an errant vehicle to hit a tree. Also, the chance of hitting the tree increases when the lateral offset of the trees from the edge of road gets smaller.

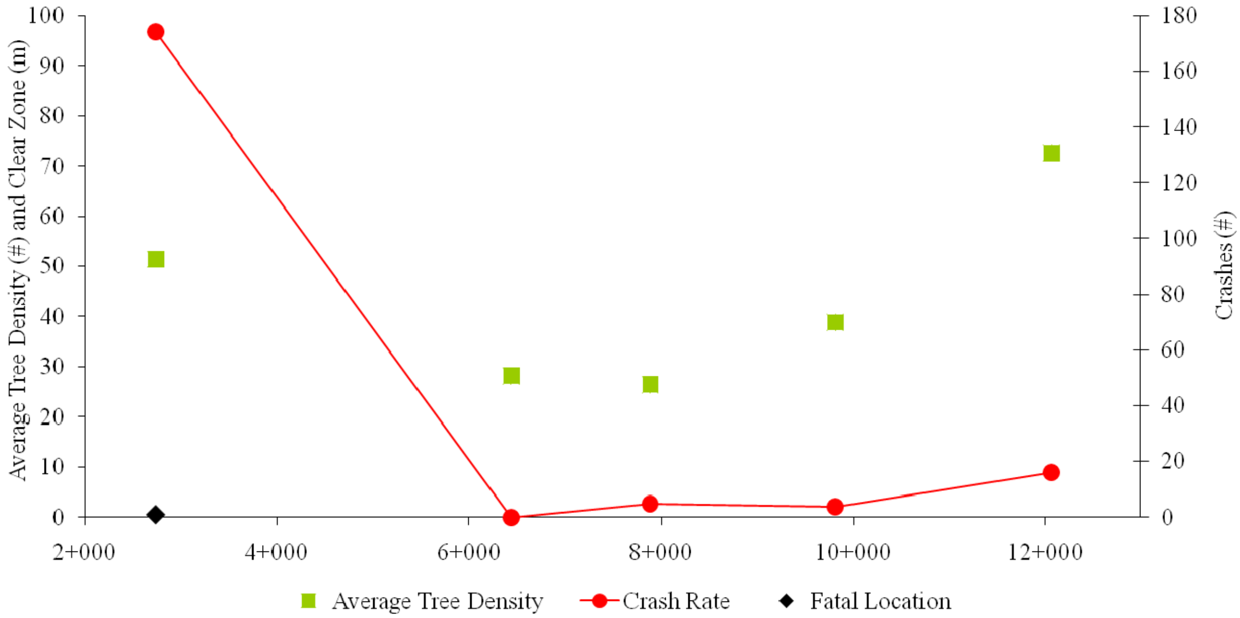

Figure 4. Comparison of average tree density with injury and fatal crash rates for each zone of Route 31 in Spencer.

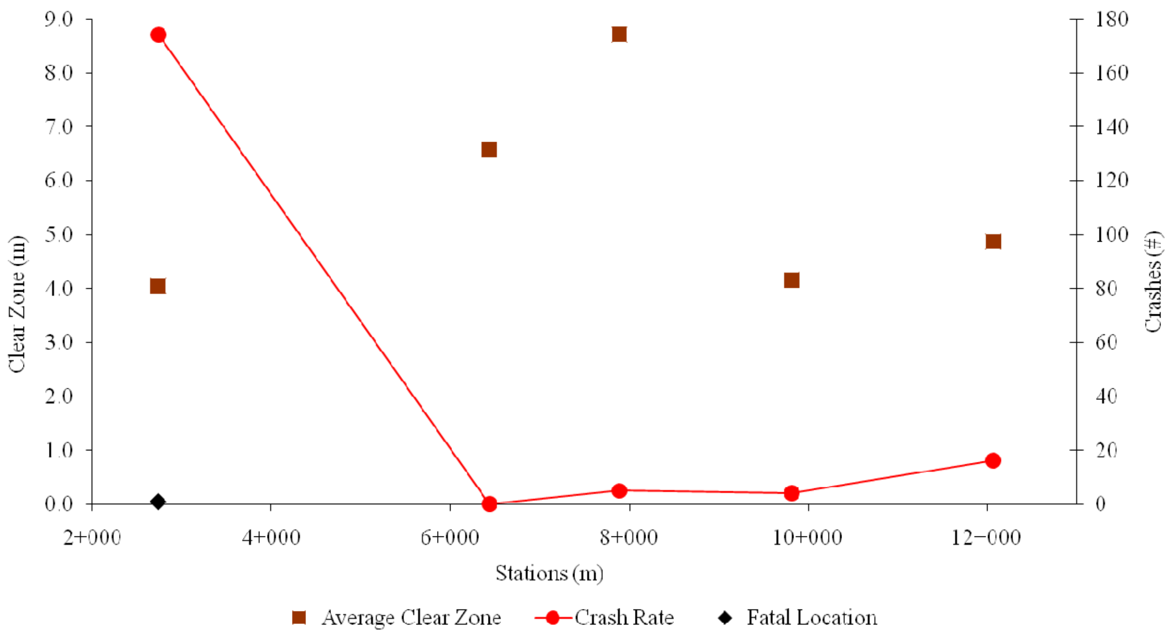

Figure 5. Comparison of average clear zone with injury and fatal crash rates for each zone of Route 31 in Spencer.

Development of a Predictor Model to Identify Contributing Factors to Tree Crashes

The second step was to define a predictive model to identify the magnitude of contribution each characteristic has on tree crash risk. A regression analysis was performed in Microsoft Excel analysis pack add-in (Microsoft 2007) for defining an equation to predict tree crash risk given the measurable characteristics listed above.

For this model values of ADT, tree density, clear zone, grade, and horizontal curvature were used as variables. The grade was assumed to be absolute since the sign of the slope depended on the direction of vehicle travel and crashes can occur in either direction. The clear zone and tree density values for the left and right sides of the road where averaged and considered as one value for each station in the analysis. The Massachusetts model is as follows:

$$y = -128.61 - 0.00717x_1 + 104.6773x_2 + 19.47588x_3 - 5.5448x_4 + 3.050794x_5 – 0.00175x_6$$

Where:

y	Crashes per 100 million vehicles kilometers traveled
x_1	ADT
x_2	Tree Density
x_3	Grade
x_4	CZ
x_5	Speed Limit
x_6	Horizontal Curve

The segment crash predictions made by this model are shown in Figure 6 for all segments of Route 31 in the town of Spencer. The model predicted crash rates for 0.161 km sections of road. When adding a polynomial curve of 6^{th} order to the predicted crash rates values, it appears that the model is able to locate the segments of the road with a higher tree crash risk. In fact, the predictive curve rises in the first zone where a high concentration of tree crashes was observed in the 2005 crash data. Also, it predicts the last segments as having an increase in risk, as supported by actual crash data. Notably, the model recognizes that the “Downtown” area is the least risky of the zones.

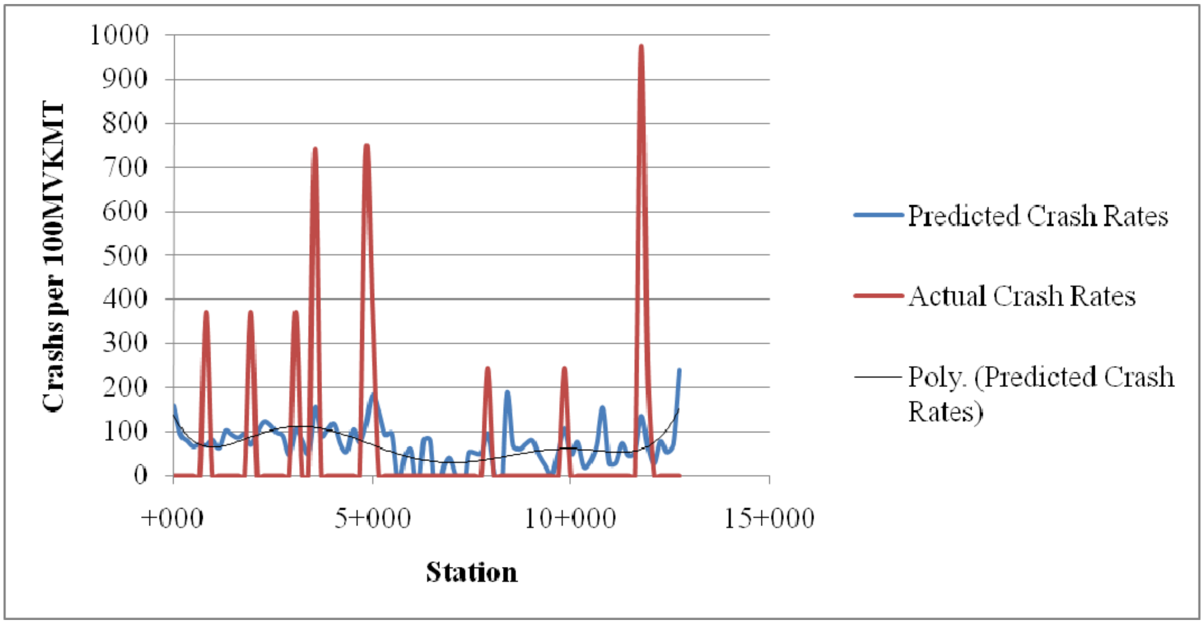

Figure 6. Actual Crash Rates verse Predicted Crash Rates.

An examination of the coefficients shows that their impacts on the predicted rate were anticipated. Table 3 shows the impact each variable and its coefficient has on the predicted crash rates over the range of collected data. For example, when the tree density is zero (e.g., there are no trees) the impact of that variable is zero. When the clear zone is zero (e.g., the trees are located at the edge of the road), the variable does not impact the crash rate, however, as the clear zone increases, the variable decreased the predicted crash rate. Therefore, as the clear zone increases, the road becomes safer. Notably, the vertical grate of the road and the traffic appear to impact the crash rate more than the curvature of the road. As the traffic increases, the predicted risk decreases. This could indicate, when examined in conjunction with the speed data, that when traffic volumes are heavy, traffic is traveling slower, therefore reducing tree crash risk.

Table 3: Summary of variable contributions to crash rate predication.

Variable	Magnitude Range		Exponent	Range of Individual Contribution	
	LOW	HIGH		LOW	HIGH
Density (trees/7 meters)	0.0	1.15	104.6773	0	119.63
Horizontal Curvature (meters)	0.0	750	0.00175	0	1.31
Vertical Grade (percent)	0.5	8.89	19.47588	9.74	173.14
Clear Zone (meters)	0	7.78	-5.5448	0	-43.13
Speed (km/h)	40	70	3.050794	122.03	213.56
ADT (vpd)	4600	7000	-0.00717	-32.98	-50.19
			Constant	-128.61	-128.61
			Predicted Crash Rate	0	285.71

POLICY RECOMENDATION

New Highway Design or Reconstruction

When designing a new or reconstructed route to national standards, some additional steps may be employed to predict tree crash risk along the proposed improvements. Engineers engaged in design generate design data (i.e., horizontal curvature, vertical grade, clear zone, etc.) which can be used in the model presented above or in a model generated for the region, to predict tree crash risk and isolate areas where new tree planting should be considered verses where existing trees pose an increased risk.

A level of desirable tree crash risk should be established for the region and each design should be assessed against that established risk level. In the event the risk is greater than desirable for the region, corrective measures should be taken prior to construction. These measures may include relocation of proposed tree planting to less risky areas or changes to the clear zone. If it is desirable to maintain a large number of existing trees, one may consider changing the design speed where appropriate.

Maintaining Existing Routes

Maintaining existing routes can be more challenging. Data collection and analysis time renders detailed analysis for every road virtually impossible. Keeping in mind the contribution of the model variables to the predicated crash risk, however, one can determine the impact of each of the variables on the tree crash risk and determine a rating score which can efficiently be applied to individual roadways. This rating score will allow for a “quick” assessment of regional roadways and isolation of the segments which warrant further detailed study. This “quick” assessment allows for eliminating the review of tree crash sights based solely on the occurrence of a tree crash, as the loan occurrence of one tree crash at a location does not indicate that location is at a greater risk than other locations along the road. This "quick" assessment allows for a comprehensive review of all segments to determine which segments are most at risk for tree crashes, because one should not wait for a tree crash to happen before removing or shielding the risky trees.

"Quick" Assessment of roadways involves driving the roads, identifying individual zones by their characteristics and rating each zone. The rating of each zone and ranking of the zones by their individual rating will lead to an identification of zones which require further, more detailed study.

The length of each zone will vary considerably by region. Regions with long stretches of roads with little variety may have long zones. Conversely, regions with roads whose characteristics change every fifty meters will have short zones. The zones should be homogeneous in nature. To conduct this "quick" assessment, one should consider the following characteristics of the roadway and rate them on a scale from zero through ten, ten being less risky than zero, as follows:

- The Tree Density rating shall be equal to ten minus the average number of trees per meter for the segment in question. For tree density values greater than ten trees per meter, the rating shall be zero.
- The Horizontal alignment rating shall be ten times the average radius of curvature for the segment, expressed in meters, divided by 500 meters. For radii greater than 500 meters, the rating shall be ten.
- The Vertical alignment rating shall be ten minus the absolute value of average segment grade, expressed in percent. For grades greater than ten percent, the rating shall be zero.
- The Clear zone rating shall be a value from zero through ten equal to the actual value expressed in meters. For values of clear zone greater than ten meters, the rating shall be ten.

A sum of the individual rating should be considered, for each segment, against other segments, to determine which segments should be studied further. The segments with the lowest rating should be considered first.

Example 1:
A given segment of road has the following characteristics:

- Tree density of 8 trees/meter,
- Three horizontal curves with radii equal to 300 meters, 250 meters, 200 meters,
- Vertical grade of 4%, and
- Clear zone equal to 2 meters.

The reviewer would rate the road as follows:

- Tree density rating: 10-8 = 2 Rating = 2

- Horizontal alignment rating: ((300+250+200)/3)*10/500 = 5 Rating = 5

- Vertical alignment rating: 10-4=6 Rating = 6
- Clear zone rating: Rating = 2
- Segment Rating = Sum of Individual Rating = 2+5+6+2 = **Segment Rating =15**

Example 2:
A given segment of road has the following characteristics:

- Tree density of 1 tree/meter,
- Tangent section of road,
- Vertical grade of 2%, and
- Clear zone equal to 11 meters.

The reviewer would rate the road as follows:

- Tree density rating: 10-1 = 9 Rating = 9
- Horizontal alignment rating: Rating = 10
- Vertical alignment rating: 10-2=8 Rating = 8
- Clear zone rating: Rating = 10
- Segment Rating = Sum of Individual Rating = 37 **Segment Rating = 37**

Upon determining which segments warrant further study, and the desirable tree crash rate for the region, one can collect the necessary regional field data to validate the model presented herein. Upon validating the model, the model can be applied to the collected data, as shown in Figure 6, to isolate the segments of the road which pose the highest risk and corrective measures can be taken. These measures may include, depending on the severity of the tree crash risk, increasing the clear zone, removing individual trees, or shielding areas with guardrail. This maintenance effort, of course, should be preserved until more dramatic improvements (i.e., horizontal or vertical alignment changes) can be implemented.

While speed considerably contributes to tree crash risk, little can be done to change the speed of an existing road during a maintenance project. One may be tempted to consider artificially lowering the speed by posting a lower speed limit, but this tactic is unlikely to change driver behavior without additional enforcement.

A suggestion for including horizontal curvature has been incorporated in this “quick” assessment. The Massachusetts model presented in this paper indicates the horizontal geometry of the road does not have a large impact on the tree crash risk. One should consider the characteristics of their region when employing this assessment method and consistently use the criteria which apply to that region. Horizontal curvature may not be assessed in Massachusetts. One may find that horizontal curves are impacting tree crash risk in their region and may include this suggestion. If this method where to be used in an area with relatively little changes in vertical alignment, one may consider not using the vertical alignment criterion. Regardless of the criteria used, the same criteria should be employed consistently throughout a region to ensure the final rankings are comparable.

CONCLUSIONS

This research identified that the posted speed limit, tree density, clear zone, and vertical grade of the road impact tree crash risk the most. Of these variables, tree density and clear zone are easily manipulated to provide users with a safe travel environment. This knowledge may be used by highway personal to improve highway safety while maintaining the natural environment the roadway runs through.

Using the model presented herein, designers can provide an aesthetically pleasing and safe environment through assessing proposed designs to ensure new tree plantings are property located to minimize risk and existing trees pose an acceptable level of risk.

Highway maintenance personal can use the "quick" assessment method presented herein to isolate highway segments within their region for further study and then use the model presented to determine where and when it is appropriate to shield or remove trees, rather than systematically removing trees because they have been hit by one errant vehicle.

References

AASHTO Roadside Design Guide, 3rd edition", American Association of State Highway and Transportation Officials, Washington D.C. 4-15 - 4-16.

The American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan. http://safety.transportation.org/htmlguides/default.asp. (accessed May 1, 2008).

Conron, C.E., Silvestri, C., Ray, M.H., *Using Public Information and Graphics Software in Graduate Highway Safety Research at Worcester Polytechnic Institute*, American Society for Engineering Education 63rd Annual Midyear Meeting, January 2009 (Pending).

Ivey, D. and Zegeer, C. (2004). *TRB State of the Art Report 9 Utilities and Roadside Safety: Strategies.* Washington, D.C.: National Research Council.

Massachusetts Highway Department, "MassHighway Crash Data Information," http://www.mhd.state.ma.us/default.asp?pgid=content/traffic/crashRateEval&sid=about, (accessed June, 2007).

Microsoft Excel v 2007.

Tree Crashes, Pictures and Stories http://www.car-accidents.com/collisions-crash-trees.html, (accessed December 26, 2007)

US Department of Transportation (USDOT), Federal Highway Administration, "Guide to Management of Roadside Trees," December 1986, http://safety.transportation.org/htmlguides/trees/assets/GuideMgmtRoadSideTrees.pdf (accessed August 3, 2007).